Point-contact spectroscopy of the antiferromagnetic superconductor $HoNi_2B_2C$

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Abstract

The point-contact (PC) spectroscopy study of the electron-phonon(boson) interaction (EP(B)I) spectral function in $HoNi_2B_2C$ reveals phonon maxima at 16 and 22 meV and 34 meV. For the first time the pronounced high energy maxima at about 50 meV and 100 meV were resolved. Additionally, an admixture of a crystalline-electric-field (CEF) excitation with a maximum near 10 meV and a 'magnetic' peak near 3 meV are observed. The contribution of the CEF peak in EP(B)I constant λ_{PC} is evaluated as 20-30%, while contribution of the high frequency modes at 50 and 100 meV amounts about 10% for each maxima. PC Andreev reflection measurements below the critical temperature $T_c \simeq 8.5$ K reveals two different superconducting (SC) states separated by $T_c^* \simeq 5.6$ K which is close to the Néel temperature $T_N \simeq 5.3$ K. Below T_c^* the gap Δ in $HoNi_2B_2C$ exhibits a standard single-band BCS-like behavior with $2\Delta/k_BT_c^* \simeq 3.9$. Above T_c^* the gap features in PC spectra are strongly suppressed pointing to a peculiar SC state between T_c^* and T_c, where incommensurate magnetic order develops.

Key words: $HoNi_2B_2C$, borocarbides, point-contact spectroscopy, superconducting gap, electron-phonon interaction
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By point-contact (PC) researches both the superconducting (SC) gap and the PC electron-phonon(boson) interaction (EP(B)I) function $\alpha^2_{\rm PC}F(\omega)$ can be established from the first and second derivatives of the $I(V)$ characteristic of PC's [1]. Thus the PC spectroscopy is a powerful method to study both EP(B)I spectra and SC gap behavior.

We have measured [2] PC spectra of $HoNi_2B_2C$ with pronounced phonon maxima at about 16 and 22 mV, a smeared maximum near 34 mV, and shoulder around 50 mV (Fig. 1). All these features correspond well to the phonon DOS of isostructural $LuNi_2B_2C$ [3], however the high energy part of the PC spectrum is remarkably smeared. Recently we have also succeed to measure PC spectra with well resolved high energy maxima around 50 and 100 mV (see Fig. 2). The 50-mV maximum corresponds to the maximum in the phonon DOS in Fig. 1, even shoulder at about 60 mV is resolved in the PC spectrum. The phonon maximum at 100-meV was registered for YNi_2B_2C in [3] and it was attributed to the B-C bond stretching vibrations. The low energy part (< 30 mV) of the PC spectra in Fig. 2 shows less detailed structure of $HoNi_2B_2C$ phonons as compared to the PC spectra from Fig. 1, likely due to contribution of the Cu phonons between 15-20 mV [1].

The maximum around 10 mV might be connected with CEF excitations, observed in this range by neutron scattering [4], while the maximum around 4 mV we attribute to the magnetic order disturbance (and appearance of spin disorder scattering), since it disappears above the Néel ($\sim$6K) temperature. Most of

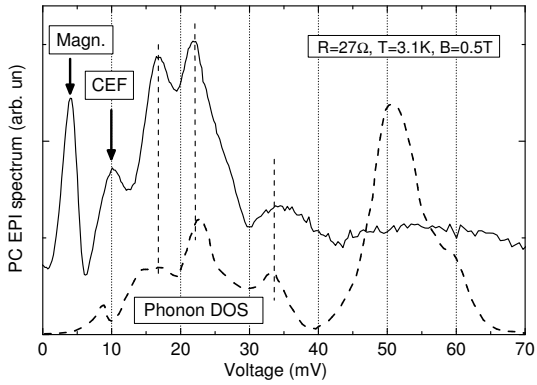

Fig. 1. PC spectrum of $HoNi_2B_2C$–Cu contact with subtracted background in comparison with the neutron phonon DOS for $LuNi_2B_2C$ [3]. Arrows mark position of CEF peak and 'magnetic' peak at about 4 mV. Vertical dashed lines mark position of the main phonon maxima in PC spectrum.

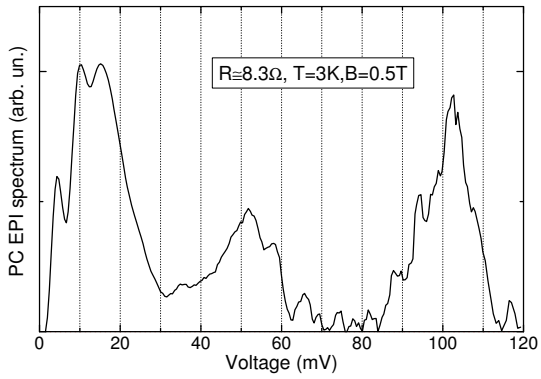

Fig. 2. PC spectra of $HoNi_2B_2C$–Cu contact with well resolved high energy maxima around 50 and 100 mV.

the PC spectra (not shown) demonstrate expressed 10-mV peak and completely smeared phonon maxima. This points to the importance of CEF excitations in the charge transport as well as in the SC properties of $HoNi_2B_2C$. Thus the contribution of the 10-mV peak in EP(B)I constant λ_{PC} is evaluated as 20-30%, while contribution of the high frequency modes at 50 and 100 meV amounts about 10% for each maxima.

The SC gap manifests itself in the dV/dI characteristic of a N-c-S contact as pronounced minima around $V \simeq \pm\Delta$ at $T \ll T_c$. Such dV/dI are presented in Fig. 3(inset). The SC gap Δ and its temperature dependence are obtained (see Fig. 3) from

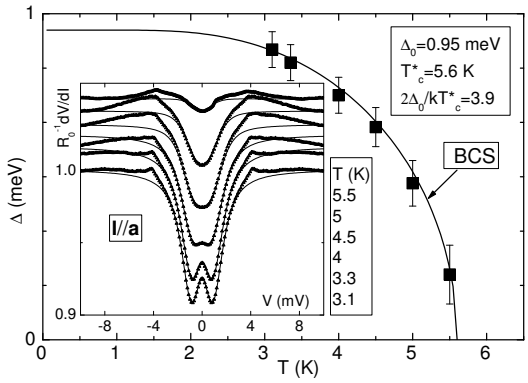

Fig. 3. $\Delta(T)$ at B=0 T obtained by the fitting of the curves shown in the inset. Inset: dV/dI curves (symbols) of $HoNi_2B_2C$–Cu contact ($R = 2.7\,\Omega$) established along a-axis with varying temperature. Solid lines are BTK fitting curves.

the fit of dV/dI by BTK equations (see [1]). It is seen that $\Delta(T)$ has a BCS-like dependence, however the gap vanishes already at $T_c^* \simeq 5.6$ K, i. e. close to the Néel temperature $T_N \simeq 5.3$ K but well below $T_c \simeq 8.5$ K of the bulk. This can be understood adopting the "Fermi surface separation" scenario for the coexistence of magnetism and superconductivity in magnetic borocarbides, i.e. a coexistence on different Fermi surface sheets (FSSs), proposed in Refs. [5]. Thus, we suggest that the superconductivity in the commensurate antiferromagnetic phase survives at a special nearly isotropic FSS isolated from the influence of the rare earth magnetism.

Between T_c^* and T_c the SC signal in dV/dI is drastically suppressed, giving no possibility to determine a finite SC gap by fitting the dV/dI data. This shows that the SC state between T_c^* and T_c, in the region of peculiar magnetic order, is 'unconventional'. We addressed the specific role of selected FSSs and CEF-excitations in this particular case.

References

[1] Yu. G. Naidyuk and I. K. Yanson, *Point-Contact Spectroscopy*, Springer Series in Solid-State Sciences, Vol.145 (Springer Science+Business Media, Inc, 2005).

[2] Yu. G. Naidyuk et al., Physica B 359-361 (2005) 469.

[3] F. Gompf et al., Phys. Rev. B 55 (1997) 9058.

[4] U. Gasser et al., Z. Phys. B 101 (1996) 345.

[5] S.-L. Drechsler et al., Physica C 364 (2001) 31; S.-L. Drechsler et al., Physica B 329 (2003) 1352.